

Knowledge management implementation in construction projects: a KM model for Knowledge Creation, Collection and Updating (KCCU)

Ahmad, Hesham; An, Min

DOI:
[10.1504/IJPOM.2008.022189](https://doi.org/10.1504/IJPOM.2008.022189)

Document Version
Early version, also known as pre-print

Citation for published version (Harvard):
Ahmad, H & An, M 2008, 'Knowledge management implementation in construction projects: a KM model for Knowledge Creation, Collection and Updating (KCCU)', *International Journal of Project Organisation and Management*, vol. 11, no. 2, pp. 133-166. <https://doi.org/10.1504/IJPOM.2008.022189>

[Link to publication on Research at Birmingham portal](#)

General rights

Unless a licence is specified above, all rights (including copyright and moral rights) in this document are retained by the authors and/or the copyright holders. The express permission of the copyright holder must be obtained for any use of this material other than for purposes permitted by law.

- Users may freely distribute the URL that is used to identify this publication.
- Users may download and/or print one copy of the publication from the University of Birmingham research portal for the purpose of private study or non-commercial research.
- User may use extracts from the document in line with the concept of 'fair dealing' under the Copyright, Designs and Patents Act 1988 (?)
- Users may not further distribute the material nor use it for the purposes of commercial gain.

Where a licence is displayed above, please note the terms and conditions of the licence govern your use of this document.

When citing, please reference the published version.

Take down policy

While the University of Birmingham exercises care and attention in making items available there are rare occasions when an item has been uploaded in error or has been deemed to be commercially or otherwise sensitive.

If you believe that this is the case for this document, please contact UBIRA@lists.bham.ac.uk providing details and we will remove access to the work immediately and investigate.

Knowledge management implementation in construction projects: a KM model for Knowledge Creation, Collection and Updating (KCCU)

Hesham S. Ahmad and Min An*

School of Civil Engineering
The University of Birmingham
Birmingham B15 2TT, UK
E-mail: hxa626@bham.ac.uk
E-mail: m.an@bham.ac.uk

*Corresponding author

Abstract: Knowledge Management (KM) is becoming increasingly important for construction companies in order to improve their competitiveness by reducing the cost and time while improving the quality of projects. Construction projects are in knowledge-intensive environments where many interrelated components work together in a complex manner. In many circumstances, knowledge in the construction industry is mostly tacit knowledge and highly based on individuals' experiences and perceptions. These situations call for a method of managing knowledge to solve construction problems and achieve a high quality of construction projects. Various kinds of KM models have been developed to support KM activities. However, the existing KM models and tools are far from enough, since most KM models only provide a communication platform and much creative knowledge work still depends entirely on human activities. This paper presents a new KM model that overcomes such shortcomings and provides an effective and efficient way of managing knowledge in the construction industry. A case study collected from the industry is used to demonstrate how the proposed KM model can be used to improve the industry's KM performance. The results indicate that the proposed KM model can facilitate the process of implementation, development and use of the KM system.

Keywords: construction project; knowledge management model; knowledge management system; knowledge-intensive environment.

Reference to this paper should be made as follows: Ahmad, H.S. and An, M. (2008) 'Knowledge management implementation in construction projects: a KM model for Knowledge Creation, Collection and Updating (KCCU)', *Int. J. Project Organisation and Management*, Vol. 1, No. 2, pp.133–166.

Biographical notes: Hesham S. Ahmad received his BSc in Civil Engineering from the Jordan University of Science and Technology and his MSc in Management Information Systems from Amman Arab University. Since then, he has been a Project Manager in a variety of construction and road projects before joining the University of Birmingham, UK, in October 2006. He is currently a PhD research student within the Safety, Risk and Reliability Management Research Group of the School of Civil Engineering and working on a project entitled 'Development of KM models to simplify knowledge management implementation in construction projects'.

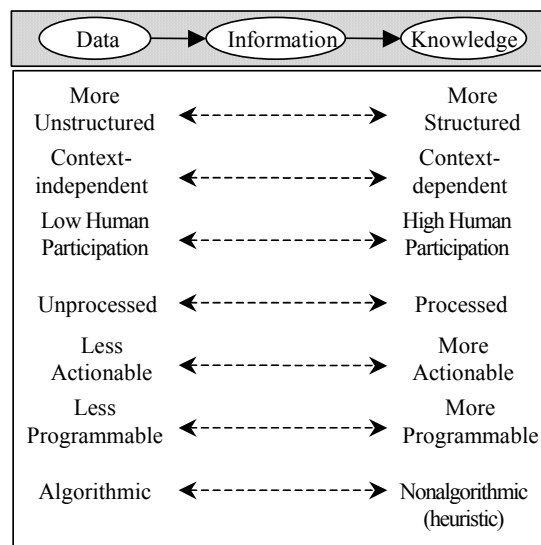
Dr. Min An (BEng (Hons), MEng, PhD, CEng, MIMechE, MCICE, MEngD) is currently a Reader in Project and Transport Risk Management at the School of Civil Engineering of the University of Birmingham (UK). He is the leader of the Safety, Risk and Reliability Management Research Group and is also the Director of the MSc/PgD Construction Management programme. He received his BEng and MSc in Civil Engineering from Xian Jiaotong University (China) and PhD in Civil and Offshore Engineering from Heriot-Watt University (UK). His research interests are in project management, safety risk assessment, project risk management and project decision-making.

1 Introduction

Knowledge Management (KM) is now considered as one of the most important parts of any organisations and it is a complement to the organisations' business activities. The main benefit by adopting KM systems in the construction work enables the industry companies to complete the projects with reduced cost and time while improving the quality of projects. By reusing and sharing previous experiences and knowledge, employees can find the solutions for their problems without spending extra time, effort and resources on reinventing solutions that have already been invented elsewhere in the organisations (Ahmad *et al.*, 2007; Bergeron, 2003).

Knowledge is the most useful form of contents for problem-solving and decision-making since it has more meaning than data and information. While data refer to raw facts without any processing or analysis and information refer to data that has been processed to be with more meaning to the users. Therefore, knowledge is more than data and information that it combines information with experiences to show methods and procedures used by others, which can be reused in the future to solve similar problems (Tiwana, 1999; Davenport and Prusak, 1998; Baker *et al.*, 1997). According to Davenport *et al.* (1998), Probst *et al.* (2000) and Awad and Ghaziri (2004), data, information and knowledge have different attributes that can be illustrated in Figure 1.

Figure 1 Data, information and knowledge attributes



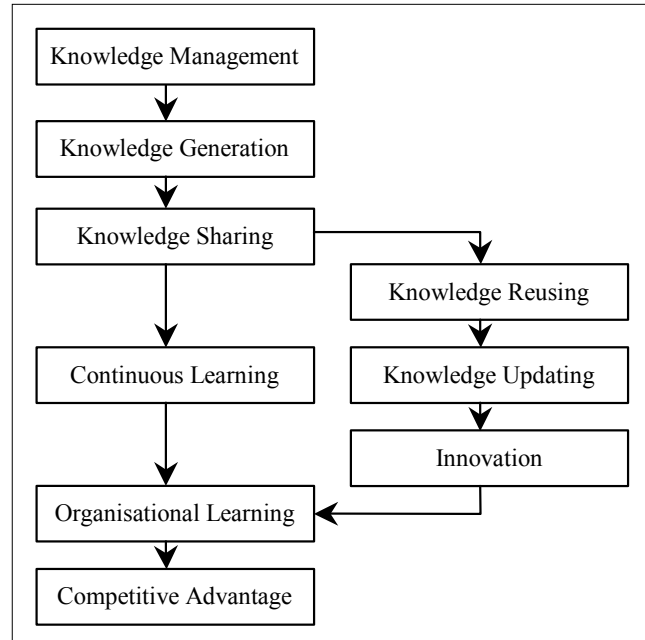
Knowledge can be defined as the facts, skills and understanding that one has gained, especially through learning or experience, which enhance ones ability of evaluating context, making decisions and taking actions (Awad and Ghaziri, 2004; Tserng and Lin, 2004). Alavi and Leidner (2001) defined a KM system as “IT-based systems developed to support and enhance the organisational processes of knowledge creation, storage/retrieval, transfer, and application.” KM systems (Gupta *et al.*, 2000) refer to a class of information systems applied to managing organisational knowledge, which helps organisations to find, select, organise, disseminate and transfer important knowledge and expertise necessary for activities such as problem solving, dynamic learning, strategic planning and decision making.

The research by Gupta *et al.* (2000), which discussed practices and challenges of KM in a number of selected organisations, argues that KM is the only competitive advantage for companies in the 21st century. The research shows that the two major trends currently used in the industry when applying KM are measuring the intellectual capital by developing measurement ratios and benchmarks, and mapping knowledge that includes capturing and disseminating knowledge of individuals, mainly through information technology. This research also shows the importance of data mining tools in transforming the organisation’s existing data into ‘answers-knowledge’ available to employees anywhere in the organisation at anytime.

Knowledge modelling is a technique that uses graphical and textual presentations to describe the real system of KM and its features, parts, inputs, outputs, tools, processes, practices and factors that can impact the organisational knowledge and the KM system (Davenport and Prusak, 1998; Abdullah *et al.*, 2002). A KM model provides a guide to implement and use the KM system efficiently and effectively. It also helps to coordinate between different people who develop or use the KM system by providing details of the different work phases and the activities to be done. Using modelling techniques can also reduce cost and time in helping people to understand the complexity of the large systems (Abdullah *et al.*, 2002). This paper presents a new KM model that addresses these issues and provides an effective and efficient way for managing knowledge in the construction industry. A case study collected from the industry is used to demonstrate how the proposed KM model can be used to improve the industry KM performance.

2 Motivations and challenges

Industrial companies can enhance organisational learning through knowledge generation combined with successful knowledge sharing (Li and Gao, 2003), which will not only lead to enrich the knowledge of employees and organisations, but also will lead to more strategic innovations. The benefits of application of KM are shown in Figure 2. Improving organisational learning means enhancing the ability of the organisation to collect and use knowledge so that members can exploit it to improve the organisation’s performance (KLICON, 1999). Organisational learning can create possibilities to gain competitive advantage, which involve the ability of a company to perform projects and activities at lower cost and time combined with high quality of projects than other competitors.

Figure 2 Knowledge generation and sharing leading to an organisational competitive advantage

The current interest in KM motivated by the improvements is that should be achieved in data processing and communication capabilities (KLICON, 1999). The increased recognition of KM is a necessary prerequisite for project success in today's dynamic and changing environment (Love *et al.*, 2003). Therefore, the industry needs for innovation, quality, business performance, efficiency of project delivery and long term relationships with partners, suppliers and clients to gain competitive advantage (Egan, 1998; Kamara *et al.*, 2002).

The industry usually faces the challenge of how to construct a well-linked KM system that allows a learner to acquire knowledge. It has been found that many challenges to KM implementation in the construction industry such as the complexity of industry, diversity of work players, adversarial relationships that encouraged by the strategy of contracting and the project nature with the pressure to complete and non-repetitive nature of work, are all causes for much 'knowledge wastage' and difficulties in accessing important knowledge (KLICON, 1999). Some empirical studies proved that construction companies, especially Small and Medium Enterprises (SMEs) which consist about 99% of construction firms in the UK, suffer lack of awareness of many important issues associated with knowledge capturing and its benefits for construction organisations (Hari *et al.*, 2005). The difficulty of KM implementation for many construction organisations caused not only by the complicated nature of KM operations, but the fact that the implementation of KM initiatives has often been unplanned and informal. A study conducted by Robinson *et al.* (2004) based on leading construction organisations showed that these organisations lack a strategy of KM implementation and coordination, and a high percentage of them have not appointed a knowledge manager or a team to implement the KM strategy with the fact that small and medium organisations are less successful than large counterparts in KM implementation. Other studies argue that

the UK construction companies with domestic operations are less successful in KM implementation of their international counterparts, because they lack the adoption of well formulated KM strategies and implementation plans, and KM alignment with business strategy of the organisation (Robinson *et al.*, 2005). A survey carried out by Carrillo *et al.* (2004), which investigated the main barriers to implementing KM strategies such as work processes, time of employees, organisational culture, expenses, resistance of employees and poor IT infrastructure, indicated that the most significant barrier to KM implementation in the UK construction organisations is the lack of the standard work processes, for example, too many different procedures to perform similar activities and the lack of systematic procedures for collecting and reusing lesson learnt and best practice. Although previous studies attempted to select or to develop an appropriate KM strategy for the construction industry, managerial courage is required to face this challenge and achieve changes.

The challenges to KM implementation and the lack of awareness of KM importance in construction organisations cause the need for a more coherent and structured approach for utilising tacit and explicit knowledge within organisations (Hari *et al.*, 2005). Many techniques have been developed and used in the construction organisations to enhance KM implementation and reduce the effect of knowledge barriers. For example, by using network knowledge maps, users can improve their ability to discover what knowledge exists and what knowledge is missed in a certain area or project (Lin *et al.*, 2006). Woo *et al.* (2004) developed a dynamic knowledge map technique that facilitates searching for experts with relevant knowledge and communicating with them by using instant messaging, e-mail, telephone, internet conferencing or other internet technologies. Most recently, KM modelling techniques have been developed for managing knowledge systems. KM models are used to help people to understand the complexity of the real systems by representing the main features and dividing the large system into its parts, to simplify understanding and managing (Abdullah *et al.*, 2002). A successful technique in construction KM is the use of Activity-Based KM systems where knowledge gained from projects are categorised and saved in units related to the activities of projects so that these knowledge can be easily retrieved and reapplied (Tserng and Lin, 2004). Another technique of knowledge categorisation and organisation is the use of Ontology-based systems. Ontology is an explicit specification that provides formal representation to show what knowledge of a domain exists in a knowledge-based system, which enhances searching capabilities, enabling the segregation of knowledge and reducing the overlapping topics between different discussion groups (Gruber, 1993; KLICON, 1999). This technique provides a mechanism to classify domain knowledge items into inter-related components in the form of hierarchical structure and semantic relationship in which knowledge can be accessed based on meaning, better enabling computers and people to exchange these knowledge (El-Diraby and Kashif, 2005). However, these techniques and many other ongoing researches need a more structured coherent approach to KM and a better alignment of KM to business goals in the construction organisations.

Recent literature classifies knowledge within an organisation into two categories, *i.e.*, explicit knowledge and tacit knowledge. Explicit knowledge can be expressed in formal and systematic language and shared in the form of data, scientific formulae, specifications, manuals and such like. Tacit knowledge is highly personal and hard to formalise, which includes subjective insights, intuitions and hunches (Nonaka, 2007). Explicit knowledge is easy to be captured, retrieved, shared and used because it can be

expressed in words and numbers that can be managed more easily. Tacit knowledge is personal and exists in the individuals' heads and memory in the form of experiences and know-how that is not easy to be shared and managed. However, tacit knowledge can be captured, mobilised and turned into explicit knowledge, which would be accessible to others in the organisation and enable the organisation to progress rather than have its members having to relearn from the same stage all the time (Gore and Gore, 1999). Many of the existing KM techniques and tools can only deal with explicit knowledge, but many studies have approved that tacit knowledge is playing an important role of KM in the organisations. Therefore, it is essential to develop a new KM model that can be used as a navigation aid to explicit and tacit knowledge to satisfy the needs of the industry. This study also addresses this problem by developing a new KM model that can deal with both explicit and tacit knowledge.

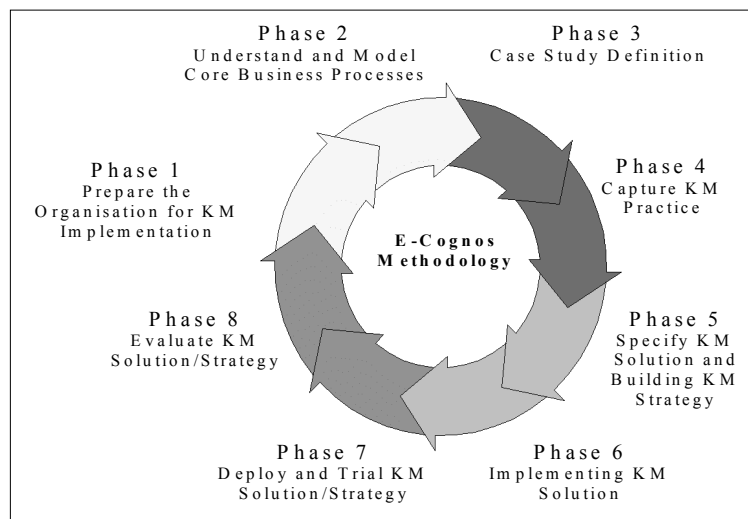
3 Review of KM models

A KM model developed in the E-Cognos project (Ferneley *et al.*, 2002; Lima *et al.*, 2005) aims at promoting consistent KM within collaborative construction environments (E-Cognos is an European R&D project for electronic consistent KM across projects and between enterprises in the construction domain). The E-Cognos platform presents the first comprehensive ontology-based portal for KM in the construction domain that provides adequate searching and indexing capabilities and allows for formally documenting and updating organisational knowledge. The proposed approach is described by Wetherill *et al.* (2002) as a cyclic approach as shown in Figure 3 which consists of eight phases: preparation of organisation for KM implementation, understanding and modelling core business processes, case study definition, capturing KM practice, specification of KM solution and building KM strategy, implementation of KM solution, KM solution trial, and evaluation of KM solution. This model can provide feedback that promotes for a new iteration of the KM phases that lead to refine and improve KM system. This model addresses the knowledge requirement of end-users and supports their existing practices while taking into account the contractual, legal, intellectual property rights, security and confidentiality constraints. In this KM model, the knowledge is divided into three categories: the domain knowledge, organisational knowledge and project knowledge. However, this model ignores a number of important issues such as knowledge acquisition, classification, storing, reusing and updating, in particular, the identification of the two types of knowledge, *i.e.*, explicit and tacit knowledge, which require different methods, tools and processes to capture and manage. Furthermore, it is also necessary to identify the important factors that affect construction activities such as culture and management strategy.

The research and development of KM work carried out by Skanska Group (one of the world's largest construction companies with about 56 000 employees and a leading position in a number of home markets in Europe, the USA and Latin America) is to link together knowledge-bearers at business units and external specialists with other organisations who involve Skanska's projects. A knowledge network has been established and knowledge maps are applied to facilitate the exchange of experiences, reduce risks of projects and enhance the performance of each business stream via knowledge exchange between different business units and different geographic markets (Axelsson and Landelius, 2002; Skanska, 2007). This KM model has been developed

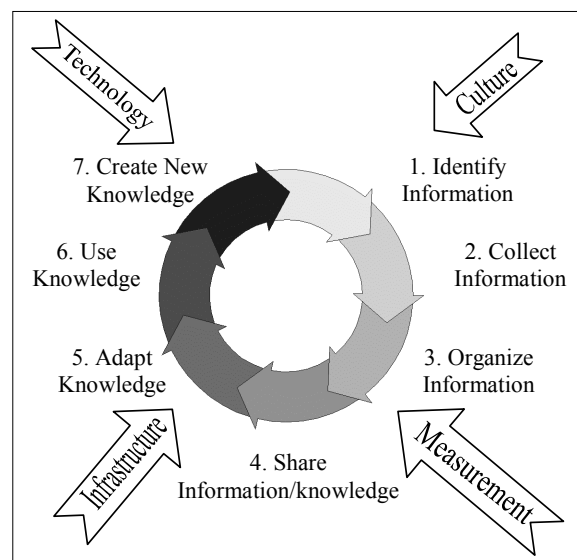
according to using O'Dell and Grayson's (1998) KM model, which consists of seven steps as shown in Figure 4 such as information identification, information collection, information organisation, information sharing, knowledge adaptation, the use of knowledge, and creation of new knowledge. This model emphasises the importance of the supporting employees to adopt and use knowledge, but it is unclear the roles of the management. This model also does not show the classification of explicit and tacit knowledge which need to be dealt with in the different ways efficiently and effectively.

Figure 3 The e-COGNOS KM model



Source: Wetherill *et al.* (2002)

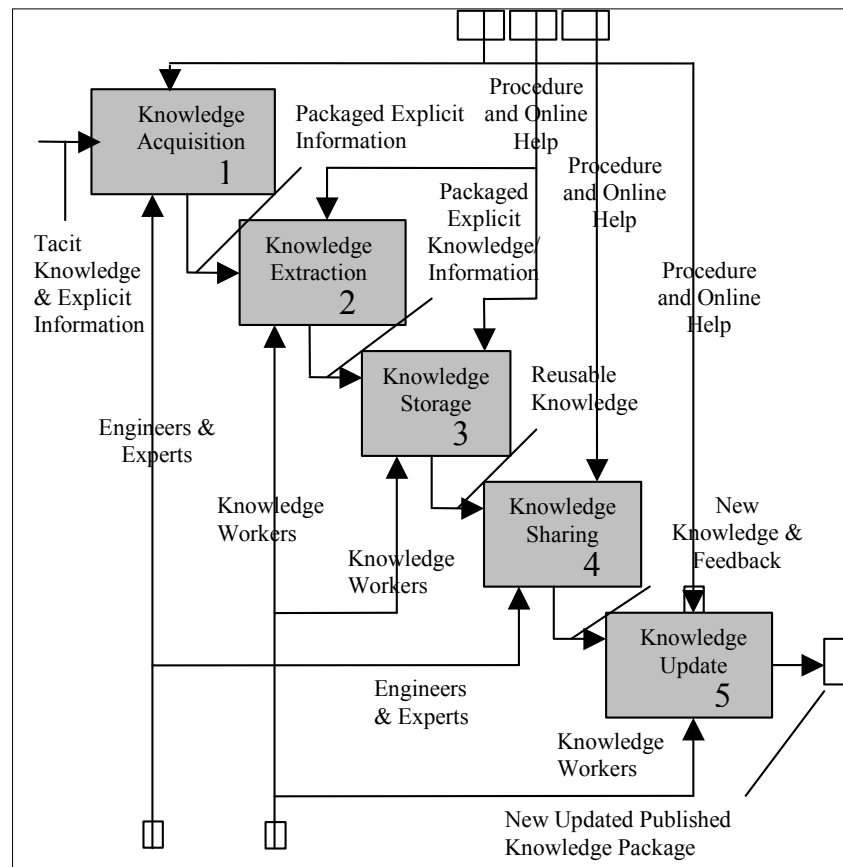
Figure 4 Steps in the knowledge transfer process in a knowledge transfer-enabling environment



Source: O'Dell and Grayson (1998)

Tserng and Lin (2004) researched into the application of KM to construction projects and proposed a construction activity-based KM model for contractors as shown in Figure 5. The main advantage of this model is that it simplifies the collection and reuse of knowledge in construction projects. This model represents activities and processes that are necessary for a successful implementation and use of KM system. On the basis of activity-based KM model, Lin *et al.* (2006) introduced an approach to capture and present knowledge for the construction projects by using network knowledge maps. A knowledge map is a graphical or diagrammatic representation that shows what knowledge is available and what knowledge is missing in the system in a clear and simple way. It can clarify vague knowledge and enable the users and learners to find desired knowledge easily. In this KM model, knowledge gained from previous projects is connected to knowledge map units of the similar activities of new projects. Although this model shows the importance of classifying knowledge into explicit and tacit knowledge and emphasises both of these two types of knowledge must be managed differently, there is a lack of a statement of the environmental factors such as employees' culture and management strategies that affect the application of KM in the construction projects, and this model cannot be applied to the parallel KM activities.

Figure 5 Top level of construction knowledge management



Source: Tserng and Lin (2004)

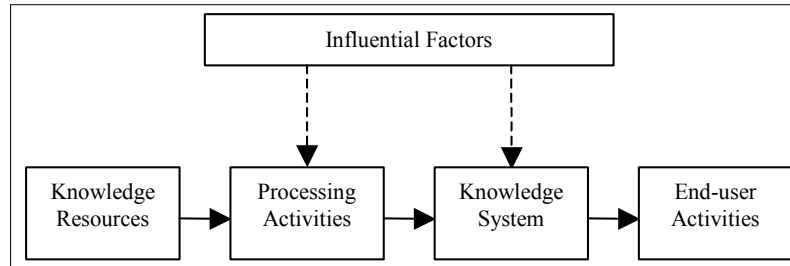
Most recently, Maqsood *et al.* (2007) applied Soft System Methodology (SSM) to a case study to show how knowledge-pull from external knowledge source could systemise knowledge exchange as a KM initiative. The results indicate that by using this SSM technique a construction contractor can receive a lot of benefits from a chosen approach, for example, to participate in the external knowledge activity for delivering significant benefit from diffusing an external developed innovation. Seven sequential steps of the developed SSM model aim to explore problematic situations that arise in human activities by learning from the different perceptions that exist in the minds of the different people who are involved in these situations. However, the research only focused on human knowledge exchange.

A study in C-SanD project (Creating, Sustaining and Disseminating Knowledge for Sustainable Construction: Tools, Methods and Architecture) carried out by Shelbourn *et al.* (2006) aims to promote knowledge creation in construction sectors for subsequent sharing and reuse. The work focuses on the promotion of sustainable development in the construction industry especially in the areas such as the minimisation of waste, material recycling and energy conservation in the design, construction and operation of buildings. The research developed a Sustainability Management Activity Zone (SMAZ) as an activity zone within the Generic Design and Construction Process Protocol (GDCPP). The DDCPP is a process map that provides a framework for managing any given construction projects through eight activity zones such as the development of project, resources, design, production, facilities, health and safety, statutory and legal, and management process.

There are many other KM models have been developed in the literature. Although some KM models help construction organisations to embrace KM, the approaches employed in the development of KM models are not targeted to explicit and tacit knowledge, which leads to difficulty during the KM implementation and application. This study proposes a new KM model that is suitable for extracting knowledge from various sources to provide a simple and practical method for KM implementation for construction projects.

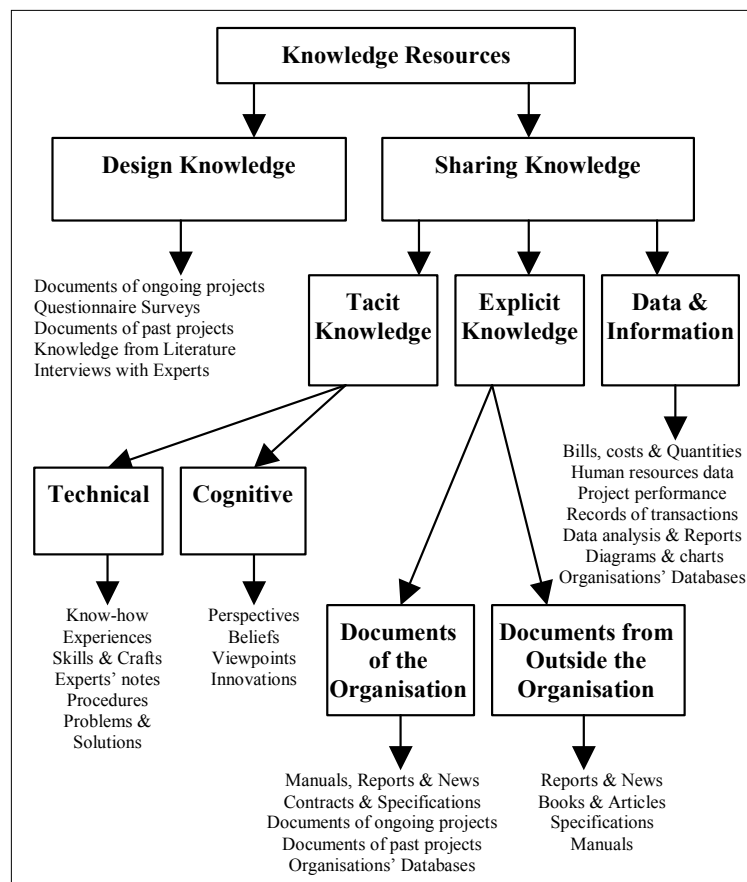
4 Proposed KM model

A new KM model has been proposed for construction projects. This model emphasises initiatives, roles and influential factors and takes the importance of integrating project information and knowledge in the organisation into consideration. By integrating knowledge it avoids re-recording knowledge that already exists in the organisation. This can minimise the existence of many pieces of knowledge that contradict each other. The new KM model as shown in Figure 6 consists of five components: knowledge resources, influencing factors, processing activities, end-user activities and knowledge system architecture that will be described in the following sections.

Figure 6 Components of the new proposed KM model for construction projects

4.1 Knowledge resources

A successful KM system depends largely on the way in which an organisation identifies the important knowledge resources available. Therefore, the proposed KM model starts with collection, organisation and review of knowledge. The knowledge will be used in the design and implementation of KM system. However, knowledge resources can be divided into design knowledge and sharing knowledge as shown in Figure 7.

Figure 7 Knowledge resources for construction projects

Design knowledge can be easily collected from the documents of ongoing and previous projects, literature, interviews and questionnaire surveys that form the main sources of knowledge which can be used in the process of analysis, design and implementation of the KM system.

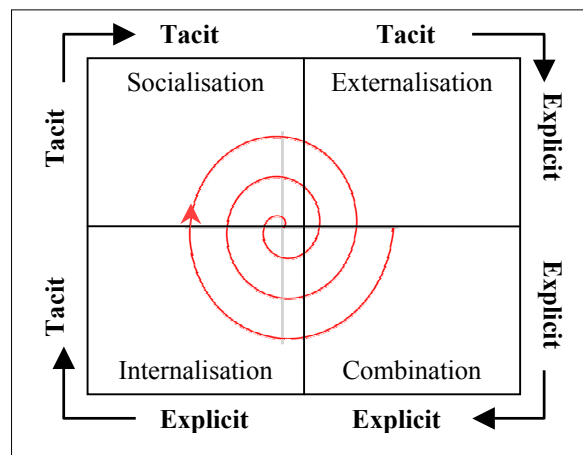
The sharing knowledge can be further broken down into explicit knowledge and tacit knowledge. The reason behind the importance of this classification is that it differentiates between such two types of knowledge with different nature that requires different processing methods and procedures to capture, share and reapply.

Once the KM has been implemented, the two types of knowledge will be available to be shared in the organisation. It is required to identify different methods and procedures in processing and managing these two types of knowledge. As stated earlier in this paper, explicit knowledge can usually be found in the enterprise paper-based and electronic documents, for example, manuals, specifications, contracts, reports, organisation's database, and also from outside the organisation such as books, journals, news and regulations. Tacit knowledge is the personal knowledge that exists in the mind of engineers and experts in the form of experiences and know-how, which is difficult to be stored and formalised. An effective method to share such tacit knowledge is through direct and indirect contacts, for example, by using e-messages, e-chats and e-meetings. But it will be useful for companies to capture and store this type of knowledge in a form of similar to explicit knowledge. Tacit knowledge can be further categorised into two types, technical knowledge and cognitive knowledge (Nonaka and Takeuchi, 1995). Technical knowledge depends on the experiences of individuals that developed with time so it can be captured in the form of 'know-how', while cognitive knowledge depends on mental models, perspectives and beliefs therefore cannot easily be articulated (Nonaka, 2007). Technical knowledge contains many shapes of knowledge such as descriptions of problems and solutions, experience notes and procedures. Cognitive knowledge includes ideas, viewpoints and innovations. However, tacit knowledge is difficult to be captured simply by normal tables, but rather they can be captured and stored in forms similar to articles including those attached descriptions, pictures and videos that provide more details and clarifications to the knowledge contents. Although this method has been proven more convenient in the collection of tacit knowledge, it needs more efforts in the classification and searching techniques to facilitate knowledge retrieving and reusing.

Nonaka and Takeuchi (1995) suggest that knowledge can be created through continuous interaction between tacit and explicit knowledge to form four modes of Socialisation, Externalisation, Internalisation and Combination (SECI). Figure 8 shows the continuous interaction that has been employed in the proposed KM model. The spiral presents the continuous movement between different modes of knowledge creation and the increase of the spiral radius shows the movement and diffusion of knowledge from an organisational low level to the high levels. Socialisation is to share experiences and tacit knowledge through direct contact among individuals. For example, an engineer can learn the tacit secrets of solving a problem from an expert or senior engineer in the construction projects (tacit to tacit). Externalisation is to transform tacit knowledge to explicit knowledge to enable its communication, for example, tacit knowledge learnt from senior members can be translated into explicit format that is easy to understand and reapply (tacit to explicit). Then the explicit knowledge is combined with other explicit knowledge that becomes available for other employees (explicit to explicit). Combination of various elements of explicit knowledge is very important in the knowledge creation

because it creates new knowledge available for other users and contributes to the knowledge base of the organisation. Finally, the explicit knowledge is transformed into experiences again by reapplying the knowledge in practice so that knowledge can be updated according to the new experiences gained. Explicit knowledge reapplied by other users can produce new experiences and tacit knowledge (explicit to tacit). These experiences and tacit knowledge can be shared among individuals through direct contacts (*i.e.*, socialisation) to start a new iteration of the continuous spiral.

Figure 8 The SECI model (see online version for colours)



Source: Nonaka and Takeuchi (1995)

As described earlier in this paper, tacit knowledge is highly personal and hard to encode. Individuals are the primary repositories of tacit knowledge that, due to its transparent characteristics, is difficult to communicate. The electronic knowledge repository has been employed in the proposed KM model. With knowledge repository technology, the organisations can capture, organise, store and disseminate tacit knowledge, for example, encouraging employees to transfer their 'tacit' knowledge to 'explicit' knowledge in the form of written reports and video presentations, building up Notes databases and making them available to other employees scattered throughout the company sites. The explicit knowledge is then saved in repositories, *i.e.*, databases and intranet web servers for the users to access.

4.2 Influential factors

Many factors affect the design, implementation and use of KM system within the organisations. These factors can be incentives or barriers for the system, and they can affect the system effectiveness, efficiency and the overall performance of the KM system. Literature search carried out by the authors (Ahmad *et al.*, 2007; 2008) indicate that these factors can be identified into five categories: *i.e.*, individual factors, organisational factors, technological factors, economical factors and customer demands. Their effects on the KM system are illustrated in Table 1.

Table 1 Knowledge management influential factors

<i>Influential factors</i>	<i>Effects</i>
Individual factors	Personal culture, such as values, norms and behaviours Level of trust among employees Motivation, training and support Commitment, communication and competencies Experience with IT and computer systems Experience with software packages and operating systems Knowledge availability from past and ongoing projects Employees' performance appraisal methods
Organisational factors	Management support, commitment and awareness Management strategy and vision Competition with other organisations Globalisation (Domestic or international organisation) Organisational structure and policy Business processes and operations Monitoring and evaluation methods
Technological factors	IT infrastructure and support systems Hardware specifications: speed, capacity and flexibility Software specifications: availability and usability of software packages, data capturing and analysis tools, and data integration tools Availability and specification of Communication and Information Technologies (CIT) Continuous change and advances in the industry Methods and tools available for KM
Economical factors	Cost of hardware, desktop, accessories and networks Cost of software procurement, implementation and maintenance Cost of knowledge management and operations Financial abilities of the organisation Level of projects' profitability
Customer factors	Increasing customers demand for: <ul style="list-style-type: none"> • Less time and cost of project and activity completion • Improved quality of products • Improved supply chain management • Improved customer relationship management • Improved response for customer's changing orders
Other factors	Legal issues Information security and privacy Governmental support Safety, health and security

Some individual behaviour such as seeing knowledge hoarding as strength, lack of trust among employees, unwillingness of showing mistakes, refusal to accept solutions from other departments or from people at lower positions, and resistance of any changes that may affect the routine operations of work, can negatively affect the KM processes and the KM system architecture in the organisation. In order to reduce the effects of these individual factors, the management of organisations have to encourage knowledge creation and sharing through the organisational rewarding systems and performance appraisal systems, and through showing commitment and providing required resources for implementing and using the KM system. The most common cultural frictions and the proposed solutions are shown in Table 2 (Davenport and Prusak, 1998).

Table 2 The most cultural frictions and the solutions

<i>Frictions</i>	<i>Possible solutions</i>
Lack of trust	Build relationships and trust through face-to-face meetings
Different cultures, vocabularies, and frames of reference	Create common ground through education, discussion, publications, teaming, and job rotation
Lack of time and meeting places; narrow of idea of productive work	Establish times and places for knowledge transfers: fairs, talk rooms, and conference reports
Status and rewards go to knowledge owners	Evaluate performance and provide incentives based on sharing
Lack of absorptive capacity in recipients	Educate employees for flexibility; provide time for learning; hire for openness to ideas
Belief that knowledge is prerogative of particular groups, not-invented-here syndrome	Encourage non-hierarchical approach to knowledge; quality of ideas more important than status of source
Intolerance for mistakes or need for help	Accept and reward creative errors and collaboration; no loss of status from not knowing everything

The support from the management of the organisation is important in managing knowledge. If managers encourage and support using and implementing KM initiatives, this will help the KM team toward developing and improving the KM system. Otherwise, it is difficult to convince managers to implement and develop a desired level of KM system.

Continuous construction change and growth in technology also affects the KM systems. The KM systems should be designed and regularly improved to satisfy such changes and improvement of construction and IT technologies. Knowledge contents should also be regularly revised and the outdated and invalid knowledge should be removed from the systems.

KM requires the use and consumption of other organisational resources. Money, time and effort are required in developing and using KM systems as well as in building the required IT infrastructure. On the other hand, the outcomes of KM not only include learning new technologies and skills but also include economical outcomes such as profitability and sales growth (Amo, 2006). The more the KM system is financially feasible, the more it inspires the organisations to join the KM field.

Customer demand is one of the important environmental pressures on KM. A major purpose of the KM system is to be flexible enough not only to meet the changing demands of customers but also to exceed their expectations. Other factors such as

knowledge security and privacy should be regarded when implementing and using knowledge systems. Egbu (2004) encouraged companies to make balance between openness and protection of their knowledge systems. Too much openness may threaten the organisation competitive advantage, while too much protection may negatively affect the innovation process and encourage bureaucracy and hierarchy in the organisation.

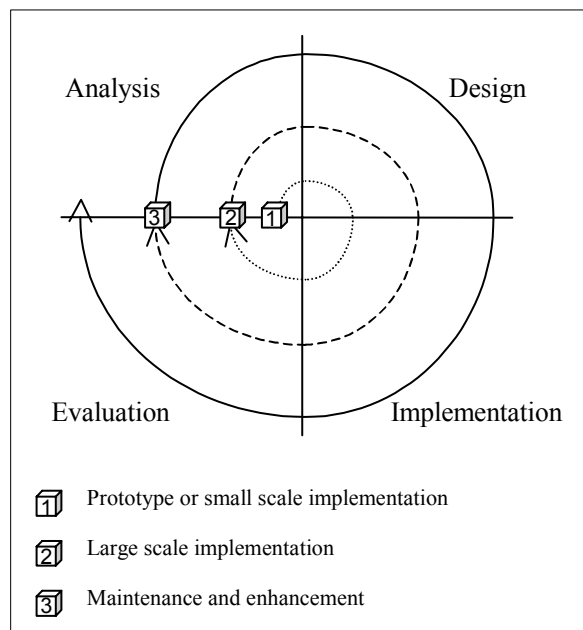
4.3 Processing activities

The proposed model presents essential KM activities in which each activity can be further broken down into sub-activities that vary according to the requirements and special characteristics of the organisations. The main activities are discussed below.

4.3.1 Processing knowledge for KM system design and implementation

Analysis, design, implementation and evaluation of KM system are a cyclic process as shown in Figure 9. Implementation of KM within the organisation starts from data, information and knowledge collection from such as interviews, questionnaires, previous project documents, regulations and literature.

Figure 9 The cyclic process of analysis, design, implementation and evaluation of KM systems



The objectives of the analysis phase are to understand the real status of the organisation and identify the desirable and feasible options for improving work process and performance. The aim is to identify vision of the organisation top management, roles and culture of the employees, and existing business processes and operations that should be understood and considered when designing the KM system. Identification of the option available for improvement of KM system includes understanding the types

and forms of knowledge available and necessary for the organisation to be collected and shared. An effective way to perform the analysis phase is to establish a KM team dedicated to this purpose to examine challenges and potential problems that the organisation may face in planning, building, maintaining and evaluating the KM system. The more the efforts spent during the analysis phase, the more the design alignment with business strategy and organisational objectives. It is important to perform a high quality analysis at the early stages of KM system development to reduce the cost and effort of re-designing and re-building inappropriate parts of the KM system. Preparation of detailed and proper analysis is the most effective way to implement KM so that the full potential of the KM system can be exploited.

In the analysis phase a set of needs and requirements (the output) can be established, which are converted into the appropriate design of the KM system. The design phase requires transferring the organisation's needs and requirements into technical specifications. In the design phase, the effective methods and tools to capture, create, categorise, disseminate, search and share knowledge should be determined. An effective action plan and a set of guidelines should be prepared to provide a step by step approach and details for KM implementation and evaluation to show the relationship among KM initiatives. The system specification, the component of the architecture, the KM services and the interface details also need to be determined in the design phase. This will provide an appropriate platform to deal with the organisation's requirements. The design phase is very important for the organisations that intend to implement the KM system in order to avoid implementation errors and gain other benefits in terms of time, cost and effort by providing directions on the KM procedures and specific details on how those procedures should be accomplished.

In the implementation phase, the design is transformed into the form that will be used by end-users. This phase is the actual application of the plans that are made in the previous phases. Installing the technical part of a KM system is not enough to ensure the application effectively and efficiently. Employees should be motivated and encouraged to use the KM system. The roles should be identified and embedded in the work procedures of employees (Ahmad *et al.*, 2008). Providing KM roles and appointing KM team and/or knowledge workers are an effective way to ensure capturing the required knowledge and providing the support and training for the employees.

In the evaluation phase, the effect of the KM system on the performance of the organisation needs to be monitored in order to improve and add new knowledge into the KM system.

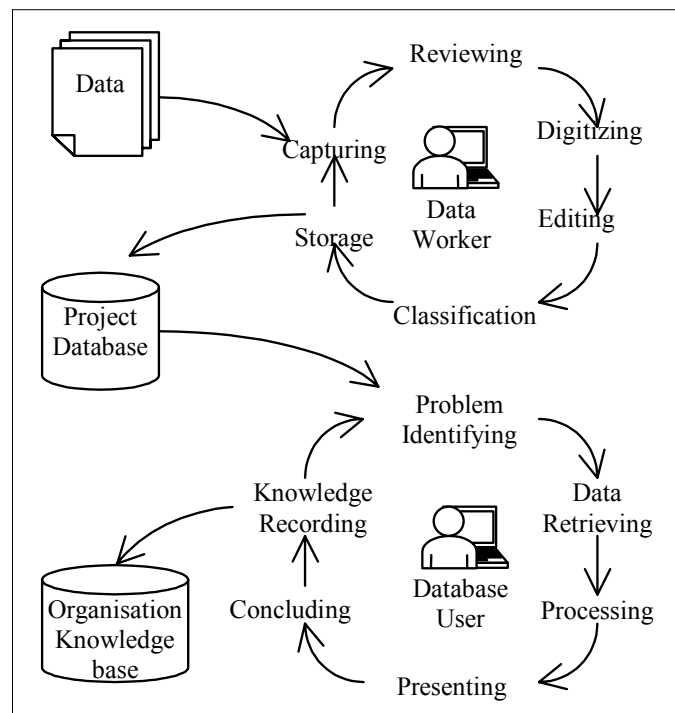
However, analysis, design, implementation and evaluation of KM system are a continuous process as shown in Figure 9 where the first iteration related to the implementation of a prototype of a small scale implementation of the KM system. The feedback from the evaluation of the prototype provides valuable information to modify the design of the system and starts a wide range implementation of the KM system. Feedback from the implemented KM system also provides information for continuous implementation of new KM parts, enhancements and maintenance of the existing system.

4.3.2 Processing data and information into knowledge

The development of knowledge bases involves various knowledge acquisition techniques to generate a body of knowledge such as historical data analysis, cost benefit analysis and domain human expert experience and engineering knowledge analysis. Knowledge

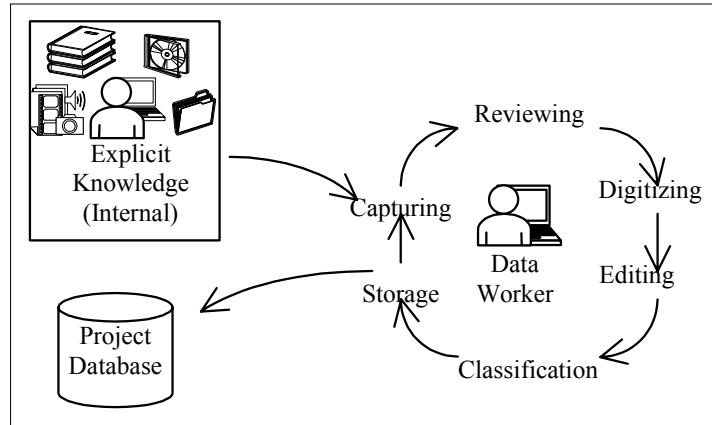
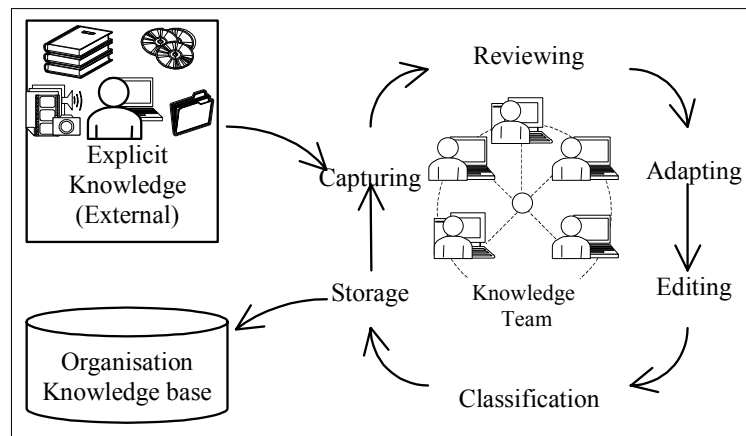
review and digitising of paper-based knowledge also have to be carried out by the KM team so that the desired knowledge can be identified and stored in the system. A database includes facts that is easy to be captured in table format but it has a little meanings. A research conducted by Rujiranyong and Shi (2006) presents the design of a project-oriented database that consists of 26 fact and dimension tables that are connected to each other through primary and secondary keys. The aim to establish a database is to capture the important operational data that is created through the life cycle of construction projects. Using data processing tools such as data mining, analysis and reporting will help to add meaning to data and transform them into knowledge that is more useful in problem solving and decision making. This will increase its value to other users. The process of capturing data and information, and transforming them into knowledge is described in Figure 10.

Figure 10 Capturing and processing data and information into knowledge



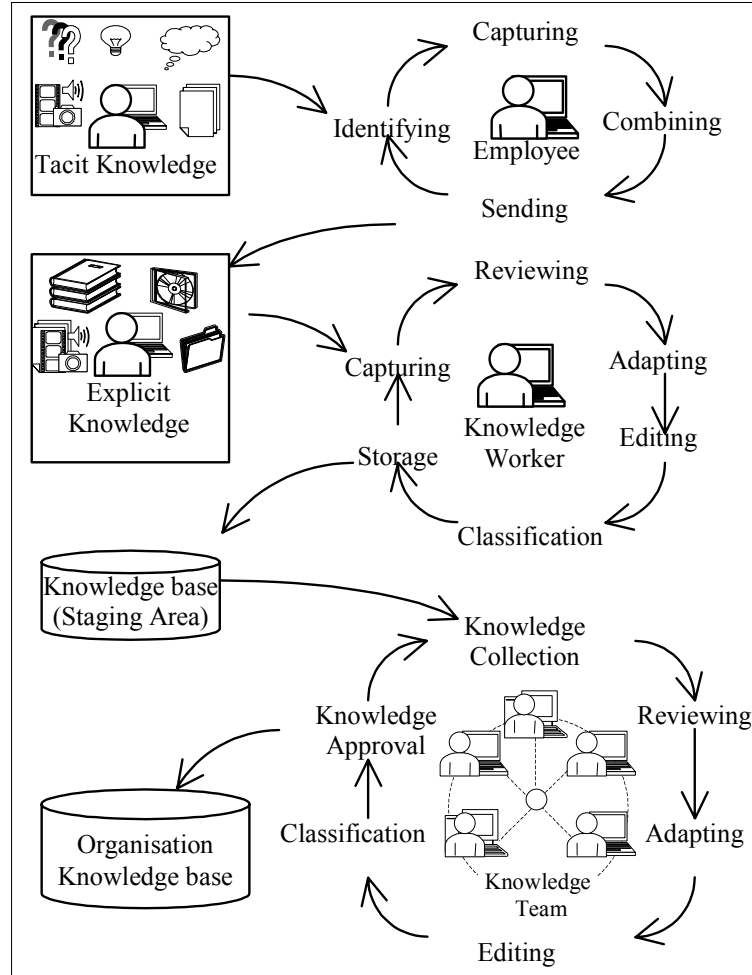
4.3.3 Processing explicit knowledge (knowledge combination)

As described earlier in this paper, explicit knowledge includes internal knowledge within the organisation, which is specific for certain departments or projects, and external knowledge from outside the organisation, which is general and can be used by different projects and departments. Explicit knowledge contains the facts that it is easily communicated and shared among employees. The process of capturing internal and external explicit knowledge is illustrated in Figures 11 and 12.

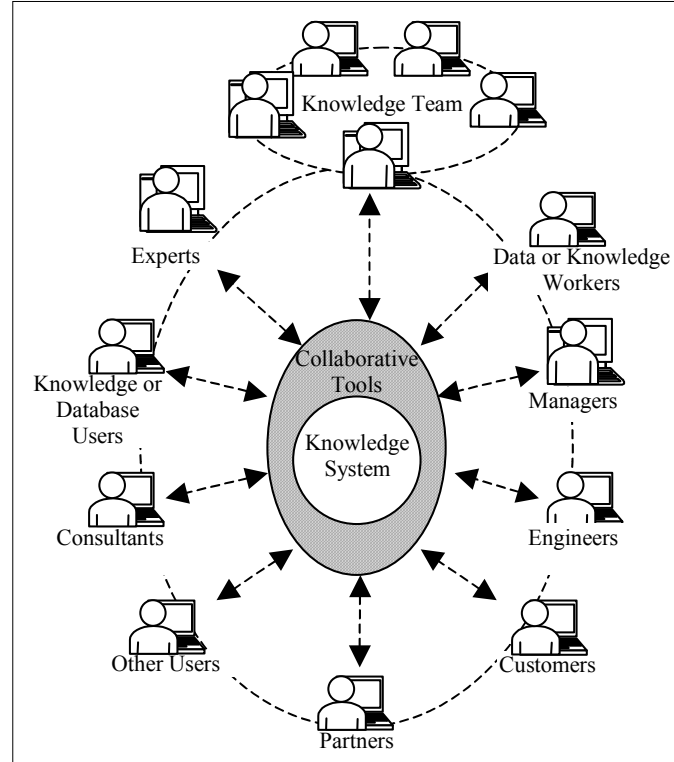
Figure 11 Capturing and processing internal explicit knowledge (knowledge combination)**Figure 12** Capturing and processing external explicit knowledge (knowledge combination)

4.3.4 Processing tacit knowledge (knowledge externalisation)

During the life cycle of construction projects a large volume of tacit knowledge are generated. The need of tacit knowledge sharing becomes important, but, unfortunately, most construction organisations have not always been successful in collecting and sharing tacit knowledge (Carrillo *et al.*, 2004; Woo *et al.*, 2004). An effective way to collect tacit knowledge is by converting tacit knowledge to explicit knowledge that is available for retrieving and reuse (Nonaka and Takeuchi, 1995). Figure 13 shows the procedures in the proposed KM model for collecting tacit knowledge and converting it into explicit. It is essential for the KM system to allow the employees in the organisation to identify and capture their knowledge into any file formats such as text, image, video, drawing, *etc.*, and then send them to knowledge workers to adapt for explicit knowledge and store in the system.

Figure 13 Capturing and processing tacit knowledge (knowledge externalisation)

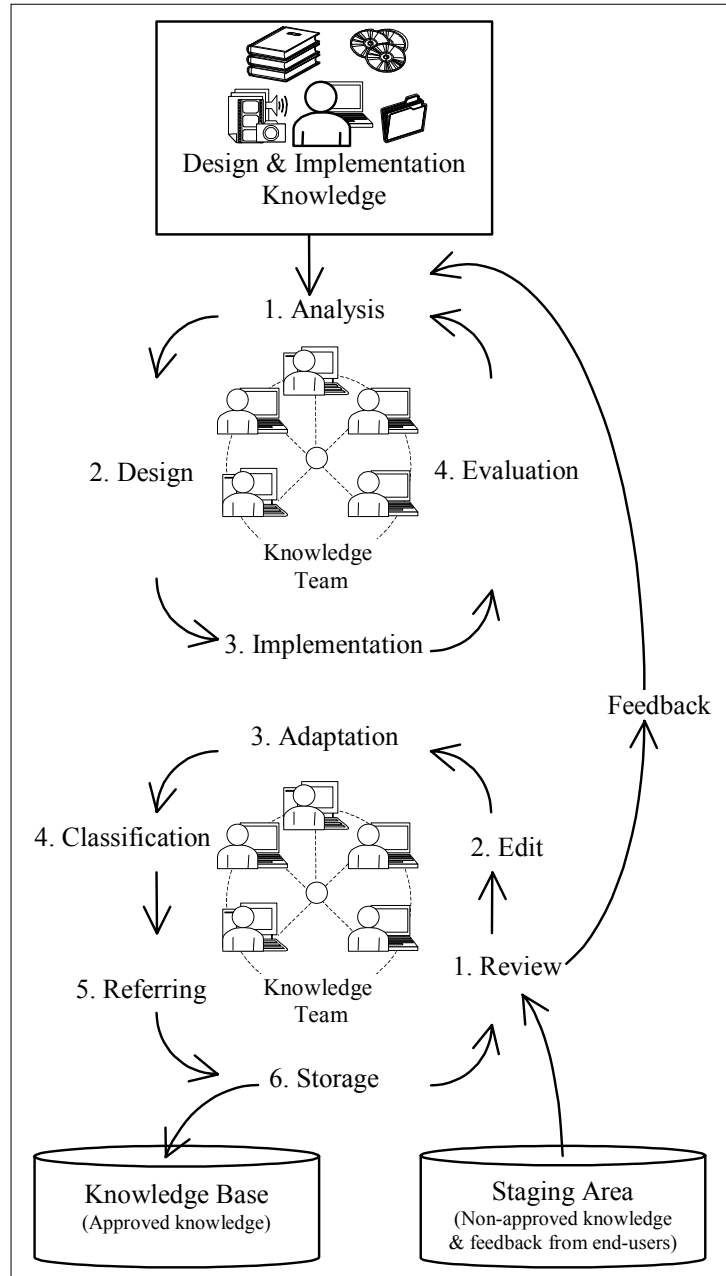
It can be essential for the KM system to capture and store knowledge in repositories, but since tacit knowledge is hard to formalise, it is very important to share tacit knowledge by connecting people through collaborative tools such as e-mail systems and Groupware. These tools aim to facilitate the exchange of tacit knowledge rather than storing it into repositories. Figure 14 shows how the collaborative tools in a KM system support sharing tacit knowledge among different players. It should be noted that the process of tacit knowledge is different from explicit knowledge as shown in Figures 13 and 14 since tacit knowledge needs more efforts in transforming them into explicit knowledge and approving them before making them available for other users and sharing them by using collaborative tools if they are not stored in the system.

Figure 14 The role of collaborative tools in sharing tacit knowledge

4.3.5 Approving knowledge

Knowledge collected by employees of the organisation needs to be reviewed and edited. Knowledge added to KM system by employees needs to be adapted in the formats that are acceptable by the system. The knowledge also needs to be classified in order to facilitate knowledge searching and reusing function. Descriptions, details, photos and videos can be attached to the contents to help better understanding and reusing the knowledge. Referring to the knowledge sources and other related knowledge is an effective technique that facilitates a comprehensive understanding of the contents of knowledge. Knowledge approval is about all the activities involved in transforming knowledge content from non-approved invalid knowledge to knowledge content valid and available for certain or all users of the KM system. Knowledge approval are a continuous process, which involves a continuous checking and testing for the knowledge contents so as to remove the outdated contents from the KM system and add new contents to the KM system. The continuous activities of knowledge approval can show the demands of the organisation to collect new shapes of important knowledge that does not exist in the system. This work with the feedback collection from end-users and the system evaluation as discussed earlier in this paper to motivate to new improvements and enhancement of the existing system is illustrated in Figure 15.

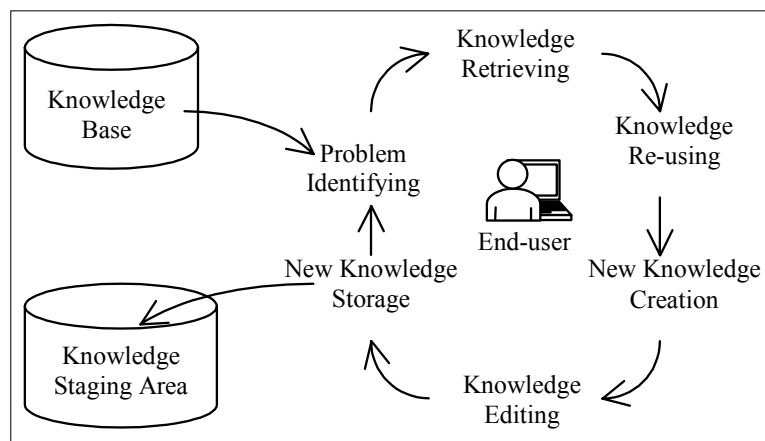
Figure 15 Knowledge approval and providing feedback for the system enhancement



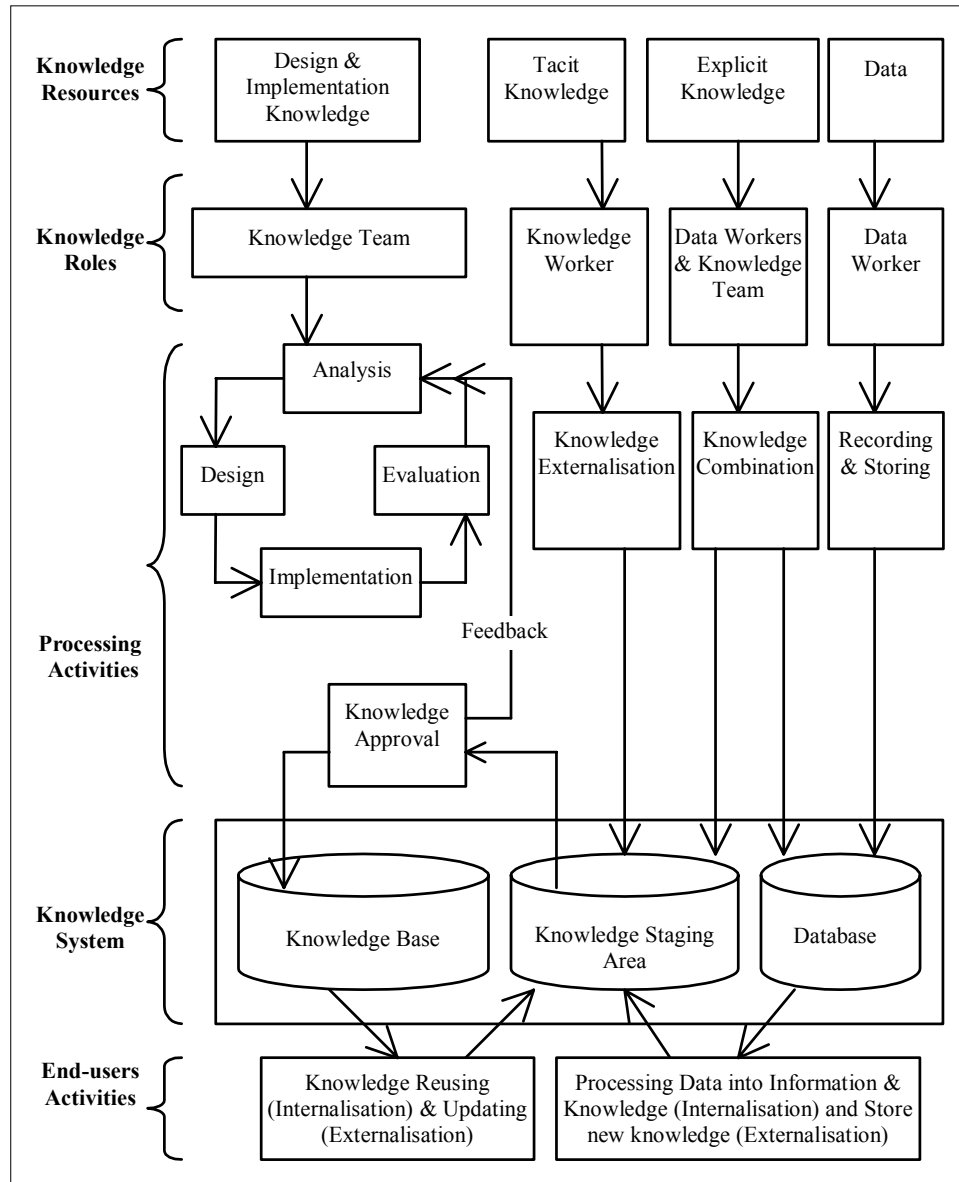
4.4 End-user activities

The KM system should address the knowledge requirements of end-users and support their existing practices while guarantee security and confidentiality. A successful KM system will provide the ability to easily find desired knowledge and contact details of the required people. Therefore, a KM system has to be designed to be available for people within the organisation with a keyword access process that defines the authority level for each user. In a certain level of authority, other users from outside the organisation are allowed to access and use the KM system in order to support the organisation relation to customers, suppliers and partners. In accordance with their authority level, end-users can update knowledge in the knowledge base by adding details, comments, relevant experiences, and removing invalid and unnecessary knowledge. Figure 16 shows the procedures of adding, updating and removing knowledge. Knowledge that come from an explicit origin such as specifications, manuals, procedures, *etc.*, can be easily updated by simply replacing the old contents with new versions. On the other hand, updating knowledge from a tacit origin such as problem-solutions, know-how, experience notes, innovations, *etc.*, needs attention to be paid because updating such knowledge requires reusing old knowledge and creating new experiences.

Figure 16 Knowledge updating

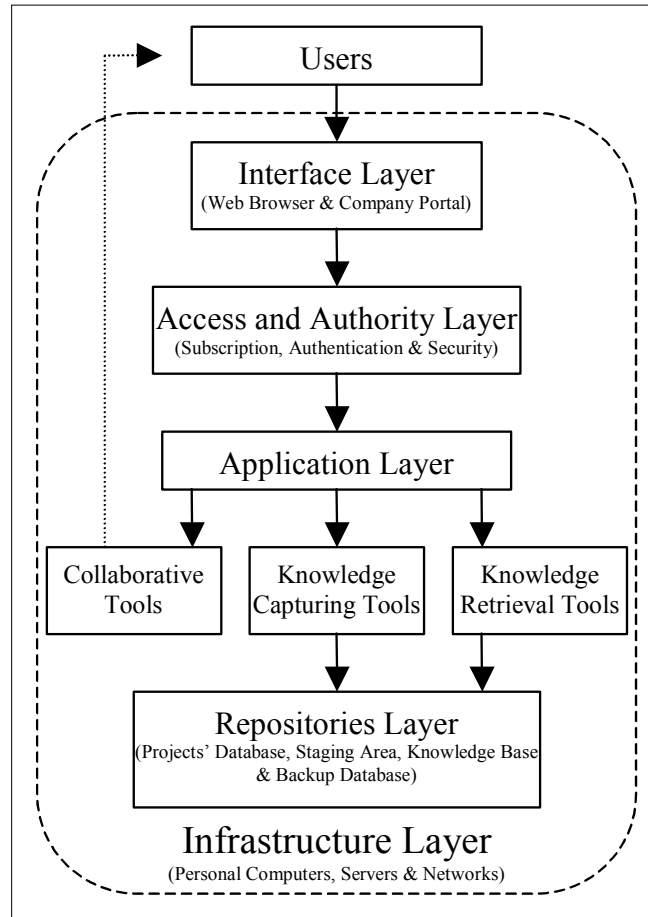


The proposed KM model for Knowledge Creation, Collection and Updating (KCCU) that combines the processes with activities is shown in Figure 17. The flow chart shows knowledge flow from knowledge resources to the end-user activities.

Figure 17 Proposed KM model for Knowledge Creation, Collection and Updating (KCCU)

4.5 KM system architecture

The technological components of the proposed KM system are divided into five major layers. Each layer includes a number of sub-layers and components that work individually or together to perform the functions of the main layers. Figure 18 shows these layers that constitute the technological architecture of the KM system.

Figure 18 KM system architecture

Interface layer is the users start point where end-users interact with other layers of the system. It provides the users with the ability to use services and tools that allow users to access and benefit from the knowledge contents of repositories. The first layer accessed from the interface layer is the access and authority layer that defines, through a user name and password system, the level of authority of the end-user and maintains the security and privacy issues of the KM system. Access layer provides users with the ability to access services and tools that are available and allowed in the application layer. These tools are classified into three types according to their functionality. Knowledge capturing and retrieval tools provide users to access to knowledge repositories to store, classify, edit, retrieve and analyse knowledge. Collaborative tools help the users to search and contact other users and experts to benefit from their experiences and perceptions. Benefits of the three categories of the KM tools are shown in Table 3. Finally, all of the layers need a compatible infrastructure that guarantees the use of the KM system effectively and efficiently at present and in the future.

Table 3 The description of services provided by the KM system

<i>Tools function</i>	<i>Tools services</i>	<i>Description</i>
Collaborative tools	E-meeting and message	Connect people through video conferencing, e-mails, e-chatting and discussion groups, which also provide the ability to record and save contents in the KM system.
	Yellow pages and contact details	Provide contact information of experts and employees with details of their professions and experiences.
	Knowledge referring	Provide the ability for KM team/workers to refer and connect knowledge package with related experts.
Knowledge capturing tools	Knowledge publishing and subscribing	Provide the ability for the KM team to publish knowledge to be shared by users, and to subscribe new users and determine their authority level.
	Knowledge classification	Provide the ability for the knowledge team/workers to categorise knowledge in order to facilitate future retrieve.
	Knowledge editing and approving	Provide the ability for the KM team to review and modify the contents of knowledge packages and approve them to be available for other users.
	Document management	Facilitate saving and recording the contents of documents and reports of projects in digital forms.
	Video, photo and drawing management	Facilitate saving videos, photos and drawings, and also facilitate attaching them to digital records to simplify understanding of contents.
	Knowledge recording and storing	Provide knowledge workers and other users the ability to record and save new knowledge of problem solving and innovations in digital format.
	Knowledge maps	Provide a way for knowledge searching and an overview of available and missing knowledge in the KM system.
Knowledge retrieval tools	Training and support	Provide e-learning to all participants in construction activities and the use of KM system.
	Knowledge searching	Provide the ability to search for knowledge by using one or a combination of keywords, expert name, knowledge domain, activity name, project name, <i>etc.</i>

The proposed KM system provides the users with different authority levels according to their positions and roles in the organisation. Table 4 shows the levels of authority provided to the end-users. The system also provides knowledge actors who are responsible for knowledge processing activities with predefined levels of authority as shown in Table 5.

Table 4 Authority levels provided by the KM system for the end-users

<i>Authority level</i>	<i>Description</i>
General level	Knowledge is available to all people and companies. It can include general information about the company and its projects as well as the services and contact details. The aim of this level is to maintain good relations with current customers and seek for new customers by providing marketing information, collecting feedback and delivering requests.
Organisational level	This level consists of many layers. Each layer can be available or unavailable for users regarding the employee job position. These layers are company specific and consist of the intellectual capital of the organisation. It includes knowledge and experience of the employees in the organisations' projects and departments. Some of knowledge are specific for employees in a certain department or a specific management positions in the organisation, and the rest is general and available for all employees. This authority level also includes a knowledge layer that is available for certain customers, suppliers or partners in order to maintain a good coordination and long term relationship.
Project level	Knowledge is specific and available for the employees in a certain project. It includes knowledge about this project. Data and information about the project such as quantities, bills and performance, and the project documents such as specifications, tenders, reports, records, problems and solutions. This knowledge, used by the project employees, forms an important source of the knowledge that has been identified.

Table 5 Authority levels provided by the KM system for knowledge capturing and processing

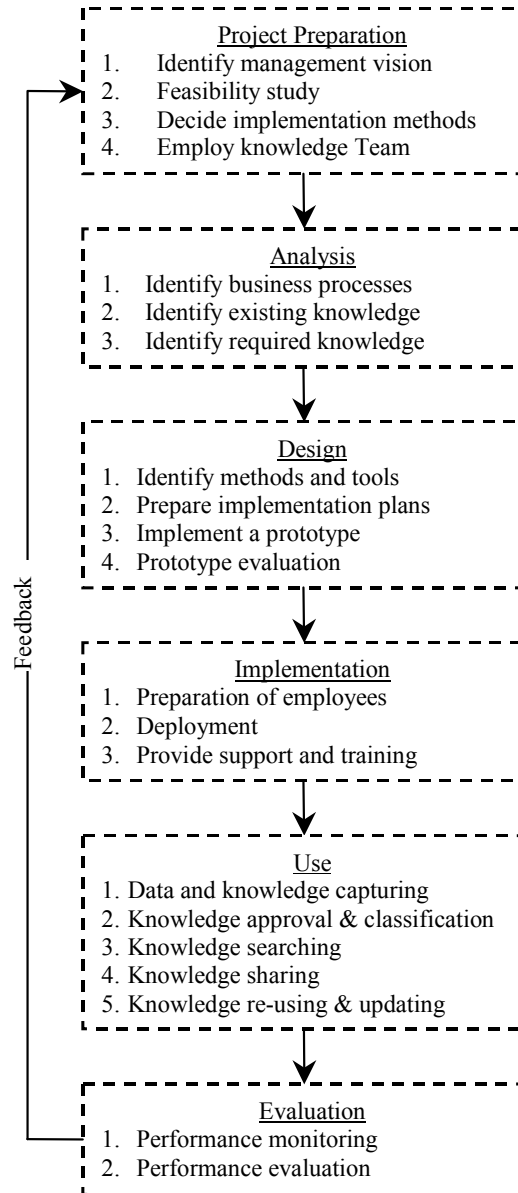
<i>Authority level</i>	<i>Description</i>
Data entry level	Include tools and services that is available for certain employees to collect, review and edit data in the tables that form the organisation database.
Data analysis level	Include tools and services that allow users to retrieve, analyse and conclude from the data stored in the organisation database.
Knowledge entry level	Provide users with the ability to add knowledge from documents, files, databases or experience to the knowledge base with the ability to attach related files, photos or videos.
Knowledge editing level	Allow users to review and edit non-approved knowledge and make this knowledge available to other users, <i>e.g.</i> , classifying knowledge, referring to knowledge sources, and adapting knowledge (putting knowledge in a format that is acceptable by the system and the users).

5 Case study

A case study conducted in the UK construction industry has been carried out to evaluate and validate the proposed KM system. In the case study, a contractor with more than 6500 employees and many years of experience involving highly sophisticated construction projects was selected to apply the proposed KM system. After four years of applying a KM system the contractor decided in 2004 to improve the existing KM performance by applying the new KM model as described in Section 4. A KM team has been established and the roles of the team have been set up to capture, store, categorise, approve, and create new knowledge from the projects. The team also provides support,

encouragement and training programmes to the employees to effectively use the KM system and share their knowledge with other employees. Training programmes have been conducted to enhance the employees' awareness about the future advantages of capturing and sharing knowledge and experiences. Supporting employees in using the KM system tools and services are provided to reduce the time and effort required by employees to learn the new procedures of the use of the new system. New services have been added to the system especially to capture tacit knowledge in the form of experiences, problem-solution, know-what and know-how. The document management system enhances to capture explicit knowledge in the different forms such as reports, manuals, specifications, drawings, scans, photos, videos and e-mail messages, *etc.* Other tools of sharing knowledge are also employed such as e-meeting, e-chatting and e-discussion tools to help employees to interact and discuss business issues. The system interface has been reorganised to make it more user-friendly. Furthermore, two knowledge maps have been developed; the first one aims to provide better view for end-users about available and missing knowledge to simplify categorising and searching for required knowledge, while the second map provides a categorised representation of the existing employees in the organisation and also provides the ability to find and contact employees with the desired experiences and knowledge. Help-desk services have been improved and manuals are provided to end-users. In addition, a training service has been established to provide useful knowledge to the junior engineers to get more flexible and effective training rather than waiting to learn through the long duration of projects' life cycle. Data, information and knowledge of 32 previous projects during 2000 to 2004 have been collected and stored to enrich the contents of the implemented KM system. The organisation has implemented and used the proposed KM system according to a procedural process as shown in Figure 19.

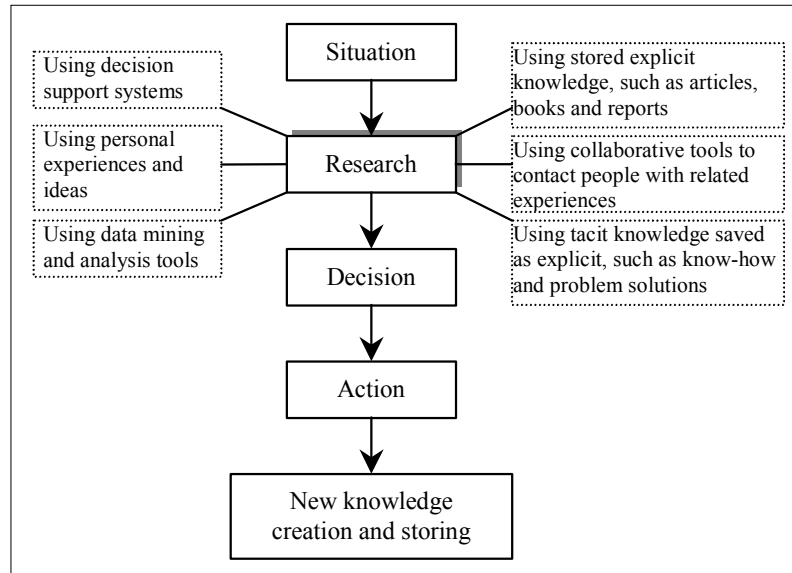
In order to evaluate the proposed KM system, data and information of these 32 previous projects are used to compare their performances before applying the KM system with after enhancing the KM system. The information of projects used in the evaluation of the proposed KM system is based on 17 medium and large size construction projects in the period of 2005 to 2007, which need experiences in different domains such as highways, bridges, soil excavations and buildings. It has been found these projects faced many problems before applying the KM system due to the complex and diverse situations. The fact is that the solutions of these problems could not be easily found from the similar previous projects. This caused remarkable delays of these projects. According to the results of information analysis from project databases, six projects were delayed about one week, five projects were delayed about two weeks, three projects were delayed about three weeks and two projects were delayed about a month, which indicates that 50% of the projects in the period before applying the KM system were completed behind the expected dates of completion. Engineers and managers find that many problems associated with projects could be avoided and they believe that the ideal solutions could be found for these problems by enhancing the KM system. Data analysis of these projects shows that the percentage of projects were completed behind the planned dates of completion have been reduced to less than 30%, *i.e.*, five projects after applying the proposed KM system.

Figure 19 Procedural process for KM implementation

The selected users have been asked to provide feedbacks about usefulness of the KM system by participating in interviews and answering questionnaires. Interviews with two project managers, four senior engineers and three knowledge workers have been conducted on the construction sites to discuss and collect their opinions about KM issues, which provide important findings and details in evaluation and improvement of the proposed KM system. The interviews used open-ended questions such as what benefits are provided by the KM system; what problems can the system help to solve; what benefits can be provided by the KM system evaluation; how easily a required piece

of knowledge can be found; how important is the knowledge sharing to the problem solving; how useful to the system users are the support services and the knowledge map, what are problems or difficulties in adopting and using the proposed KM model, *etc.* The suggestions and recommendations have been recorded. Findings are summarised as follows:

- The KM system provides a great opportunity to learn experiences from previous projects. Although the system is not designed to make decisions for users, it provides knowledge in assistance of decision-making.
- The system helps to raise the company competition, enhances work quality and reduces costs and time required in projects by providing problem solutions and reducing the probability of mistakes.
- The system provides a useful tool for training junior engineers.
- The new system helps to solve problems of losing knowledge and experiences of engineers and experts when they leave the organisation, and helps the company to keep their knowledge and experience within knowledge bases.
- Feedbacks from the evaluation of the KM system provide very useful knowledge for the improvement of the management system.
- The new system provides a great help to the users to find problem solutions and required knowledge.
- Knowledge sharing is important and useful in construction projects where there are many interrelated components working together in a complex manner.
- The KM team and knowledge workers found that the proposed system is a useful tool in supporting to their employees, which is easy to maintain and update the knowledge in the knowledge base.
- A knowledge map is a powerful tool that provides an overview of existing and missing knowledge and facilitates problem solving through finding appropriate knowledge and experts.
- Although the KM model is found to be comprehensive, it is found that it is not easy to follow without reading the instruction carefully. This provides a demand for further development and modification of the proposed KM model by dividing the model into a number of parts to enable the users to understand and follow so that the proposed KM model can be used in practice more efficiently and effectively.
- The proposed KM model should be improved to satisfy the needs of the industry, because it sometimes requires considerable changes in the organisation to be implemented in terms of culture, strategy, processes and technology.
- Finally, the KM system provides accurate and timely knowledge that facilitates the process of decision-making. The phases of decision-making used by employees are shown in Figure 20. It demonstrates how KM tools can help in the process of decision-making and lead to create new knowledge. This new created knowledge can be stored in the knowledge base and reused in the future to solve similar problems. This reduces time, cost and effort of reinventing solutions that have been invented previously in the organisation.

Figure 20 The role of KM in decision-making

The interviews show a number of important challenges for applying the KM system in construction projects. The resistances of employees to learn new methods of using the KM system, to share their knowledge with others and/or to accept solutions from others are major problems that may negatively affect the KM system. Privacy and copyright issues can sometimes prevent useful knowledge from being captured and shared in the KM system. The tendency of many employees to hoard their mistakes minimises the ability to learn from these mistakes and increases the ability to fall in the same mistakes in the future projects. Finally, the pressure of the construction projects toward finishing according to a tight schedule that makes the people feel they lack the time to use the KM system.

Evaluation of the proposed KM system has also been carried out by using questionnaires to obtain the feedbacks from users regarding the performance of the system. The results of the questionnaires provide feedback from the selected users about the system usability and usefulness. The system usability includes system specification issues, for example, as ease of use, comprehensiveness, reliability, appropriateness, applicability and sufficiency. The evaluation of usefulness of the system includes assessment of benefits that the system provides to the end users such as reducing mistakes, time and cost while improving quality of the completed works, and improving decision-making, training, team working, coordination and knowledge maintenance of employees. The questionnaires used five levels of rating scale where 1 stands for strongly disagree and 5 stands for strongly agree. The participant users include four senior engineers with 15 years of experience, two senior engineers with ten years of experience, two project managers with five years of experience, two junior engineers and two knowledge workers. The weighted average score is 4.63 of usability and 4.58 of usefulness of the KM system, which indicate that the users favourably agree that the proposed KM system is feasible and applicable. The KM system evaluation results are illustrated in Table 6.

Table 6 KM system evaluation results

<i>Questions</i>	<i>Average score</i>
<i>System usability:</i>	
1 Ease of use	4.75
2 Comprehensiveness	4.67
3 Reliability	4.42
4 Appropriateness	4.58
5 Applicability	4.75
6 Sufficiency	4.50
<i>System usefulness:</i>	
1 Mistakes reduction	4.67
2 Time reduction	4.42
3 Cost reduction	4.50
4 Quality improvement	4.67
5 Decision-making improvement	4.75
6 Training	4.42
7 Collaboration	4.58
8 Innovation	4.50
9 Maintaining knowledge of employees	4.67

The evaluation has also been carried out regarding the impact of KM system on business performance in terms of its effectiveness and efficiency. Measures of effectiveness relate to the degree or the probability that target performance measures are achieved, whilst measures of efficiency reflect the ratio of expected benefit or utility per unit of investment.

6 Conclusions

Knowledge of construction management has received considerable attention in the construction industry. This paper presents the development of a new KM system and its application to a case study. The proposed KM system simplifies the process of implementation, the use and enhancement of KM system in the construction organisations. This model overcomes and solves the problems that exist in other construction KM models and emphasises the important roles of the KM team and users. It should be noted that the proposed KM system is developed based on the practices of large construction organisations, but small and medium construction companies can benefit from sharing knowledge on collaborative relationships with large companies even if there is a lack of the IT infrastructures and human resources. Network-like relationships between small and medium construction companies and large companies are becoming common. For example, a large construction project usually involves a large number of small and medium contractors (*e.g.*, suppliers and subcontractors) and they are linked into a system of industrial partnerships. Knowledge networking could yield great benefits to provide SMEs with an opportunity to share knowledge with large organisations. The advantages of the new KM system can be summarised as follows:

- Tacit and explicit knowledge are formulated in knowledge base.
- It provides a clear process of data collection and transformation.
- It has a clear factor monitoring mechanism.
- KM can be carried out in a combination of the activities required in design, implementation and use of KM system with feedbacks.
- It provides the ability of parallel activities has been implementation.
- It provides a good level of details that makes implementing and using this system easier.
- It emphasises the roles and activities of the KM team and knowledge workers in the process of KM.
- It has been designed with more suitable architecture and components.
- It provides a clear relation between the different parts and the knowledge flow.

Although the adoption and application of KM models facilitate and encourage KM initiatives, it cannot guarantee that people in the organisation are willing to share their knowledge with others or to participate in using knowledge and/or creating new knowledge. This requires the organisation to modify the processes and activities of the employees to embed the KM activities and to adopt a performance appraisal method that appreciates tasks such as knowledge sharing, reusing and updating.

The most elaborate KM system for construction projects may be quite complex due to changes in knowledge over time. A comprehensive knowledge map must be developed for subsequent studies. This study provides a platform for further development and modification of the KM model so that the proposed KM model can be used in practice more efficiently and effectively.

References

- Abdullah, M.S., Benest, I., Evans, A. and Kimble, C. (2002) 'Knowledge modelling techniques for developing knowledge management systems', *Proceedings of the 3rd European Conference on Knowledge Management*, Dublin, Ireland, September, pp.15–25.
- Ahmad, H.S., An, M. and Gaterell, M. (2007) 'Development of KM model to simplify knowledge management implementation in construction projects', *Proceedings of the 23rd Annual ARCOM Conference, Association of Researchers in Construction Management*, Belfast, UK, 3–5 September, pp.515–516.
- Ahmad, H.S., An, M. and Gaterell, M. (2008) 'KM model to embed knowledge management activities into work activities in construction organisations', *Proceedings of the 24th Annual ARCOM Conference, Association of Researchers in Construction Management*, Cardiff, UK, 1–3 September, pp.417–422.
- Alavi, M. and Leidner, D.E. (2001) 'Knowledge management and knowledge management systems: conceptual foundations and research issues', *MIS Quarterly*, Vol. 25, No. 1, pp.107–136.
- Amo, B.W. (2006) 'What motivates knowledge workers to involve themselves in employee innovation behaviour?', *International Journal of Knowledge Management Studies*, Vol. 1, Nos. 1–2, pp.160–177.
- Awad, E.M. and Ghaziri, H.M. (2004) *Knowledge Management*, Prentice Hall.

- Axelsson, M. and Landelius, H. (2002) 'An information system as an enabler of knowledge transfer – a case study of the Skanska knowledge network at Skanska AB', A Master's thesis, Department of Civil Engineering and Architectural Management, Chalmers University of Technology, Gothenburg, Sweden.
- Baker, M., Barker, M., Thorne, J. and Dutnell, M. (1997) 'Leveraging human capital', *Journal of Knowledge Management*, Vol. 1, No. 1, pp.63–74.
- Bergeron, B. (2003) *Essentials of Knowledge Management*, New Jersey: John Wiley & Sons, Inc.
- Carrillo, P., Robinson, H., Al-Ghassani, A. and Anumba, C. (2004) 'Knowledge management in UK construction: strategies, resources and barriers', *Project Management Journal*, Vol. 35, No. 1, pp.46–56.
- Davenport, T.H., De Long, D.W. and Beers, M.C. (1998) 'Successful knowledge management projects', *Sloan Management Review*, Vol. 39, No. 2, pp.43–57.
- Davenport, T.H. and Prusak, L. (1998) *Working Knowledge: How Organisations Manage What They Know*, Boston: Harvard Business School Press.
- Egan, J. (1998) 'Rethinking construction', Report of the Construction Task Force on the Scope for Improving the Quality and Efficiency of the UK Construction Industry, Department of the Environment, Transport and the Regions, London.
- Egbu, C. (2004) 'Managing knowledge and intellectual capital for improved organisational innovations in the construction industry: an examination of critical success factors', *Engineering, Construction and Architectural Management*, Vol. 11, No. 5, pp.301–315.
- El-Diraby, T.E. and Kashif, K.F. (2005) 'Distributed ontology architecture for knowledge management in highway construction', *Journal of Construction Engineering and Management*, Vol. 131, No. 5, pp.591–603.
- Ferneley, E., Wetherill, M. and Rezgui, Y. (2002) 'Toward the construction knowledge economy: the e-COGNOS project', *Proceedings of ECIS 2002*, Gdansk, Poland, 6–8 June.
- Gore, C. and Gore, E. (1999) 'Knowledge management: the way forward', *Total Quality Management*, Vol. 10, Nos. 4–5, pp.554–560.
- Gruber, T.R. (1993) 'A translation approach to portable ontology specifications', *Knowledge Acquisition*, Vol. 5, No. 2, pp.199–220.
- Gupta, B., Iyer, L. and Aronson, J. (2000) 'Knowledge management: practices and challenges', *Industrial Management & Data Systems*, Vol. 100, No. 1, pp.17–21.
- Hari, S., Egbu, C. and Kumar, B. (2005) 'A knowledge capture awareness tool: an empirical study on small and medium enterprises in the construction industry', *Engineering, Construction and Architectural Management*, Vol. 12, No. 6, pp.533–567.
- Kamara, J., Augenbroe, G., Anumba, C. and Carrillo, P. (2002) 'Knowledge management in the architecture, engineering and construction industry', *Construction Innovation*, Vol. 2, No. 1, pp.53–67.
- KLICON (1999) 'The role of information technology in knowledge management within the construction industry', Project Report of Knowledge Learning in Construction Group at the Centre for Research in the Management of Projects, University of Manchester Institute of Science and Technology.
- Li, M. and Gao, F. (2003) 'Why Nonaka highlights tacit knowledge: a critical review', *Journal of Knowledge Management*, Vol. 7, No. 4, pp.6–14.
- Lima, C., El-Diraby, T. and Stephens, J. (2005) 'Ontology-based optimisation of knowledge management in e-construction', *ITcon*, Vol. 10, pp.305–327.
- Lin, Y., Wang, L. and Tserng, P. (2006) 'Enhancing knowledge exchange through web map-based knowledge management system in construction: lessons learned in Taiwan', *Automation in Construction*, Vol. 15, No. 6, pp.693–705.
- Love, P., Edum-Fotwe, F. and Irani, Z. (2003) 'Management of knowledge in project environments', *International Journal of Project Management*, Vol. 21, pp.155–156.

- Maqsood, T., Walker, D. and Finegan, A. (2007) 'Facilitating knowledge pull to deliver innovation through knowledge management: a case study', *Engineering, Construction and Architectural Management*, Vol. 14, No. 1, pp.94–109.
- Nonaka, I. (2007) 'The knowledge-creating company', *Harvard Business Review*, Vol. 85, Nos. 7–8, pp.162–171.
- Nonaka, I. and Takeuchi, H. (1995) *The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation*, Oxford University Press.
- O'Dell, C. and Grayson, C.J. (1998) *If Only We Knew What We Know: The Transfer of Internal Knowledge and Best Practice*, New York: The Free Press.
- Probst, G., Raub, S. and Romhardt, K. (2000) *Managing Knowledge: Building Blocks for Success*, West Sussex, England: John Wiley and Sons Ltd.
- Robinson, H., Carrillo, P., Anumba, C. and Al-Ghassani, A. (2004) 'Developing a business case for knowledge management: the IMPaKT approach', *Construction Management and Economics*, Vol. 22, No. 1, pp.733–743.
- Robinson, H., Carrillo, P., Anumba, C. and Al-Ghassani, A. (2005) 'Knowledge management practices in large construction organisations', *Engineering, Construction and Architectural Management*, Vol. 12, No. 5, pp.431–445.
- Rujiranyong, T. and Shi, J. (2006) 'A project-oriented data warehouse for construction', *Automation in Construction*, Vol. 15, No. 6, pp.800–807.
- Shelbourn, M., Bouchlaghem, D., Anumba, C., Carrillo, P., Khalfan, M. and Glass, J. (2006) 'Managing knowledge in the context of sustainable construction', *ITcon*, Vol. 11, No. 1, pp.57–71.
- Skanska (2007) *Skanska Annual Report 2006*, Skanska AB, Stockholm.
- Tiwana, A. (1999) *The Knowledge Management Toolkit: Practical Techniques for Building a Knowledge Management System*, Prentice Hall.
- Tserng, H. and Lin, Y. (2004) 'Developing an activity-based knowledge management system for contractors', *Automation in Construction*, Vol. 13, No. 6, pp.781–802.
- Wetherill, M., Rezgui, Y., Lima, C. and Zarli, A. (2002) 'Knowledge management for the construction industry: the e-cognos project', *ITcon*, Vol. 7, No. 1, pp.183–196.
- Woo, J., Clayton, M.J., Johnson, R.E., Flores, B.E. and Ellis, C. (2004) 'Dynamic knowledge map: reusing experts' tacit knowledge in the AEC industry', *Automation in Construction*, Vol. 13, pp.203–207.